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(71) Applicant
Celanese Corporation, 1211 Avenue of the Americas, New York, New York, United States of America
(72) Inventors
Derek N. Yates,
John C. Presta
(74) Agent
Carpmaels and Ransford

(54) **Fibre Reinforced Composite Shaft**

(57) The invention relates to a tubular fibre reinforced composite shaft which integrally incorporates a metal sleeve or connection at one or both ends thereof, and to a method of making such shafts.

Initially a metal sleeve (6) having apertures (26) is positioned upon a mandrel (34). Fibrous material bearing a non-solidifed epoxy resin (32) is applied around the mandred (34) and around the apertures in the sleeve. Sharpened spikes (50) affixed t plates 52 are pressed through the fibrous material and into the apertures of the sleeve. Additional fibrous material (60) bearing the non-solidified resin is applied around the outer ends of the spikes. The resin is solidified to form a tubular composite shaft whereby a secure torsion-transmitting connection is made with the sleeve, and the mandrel is removed.

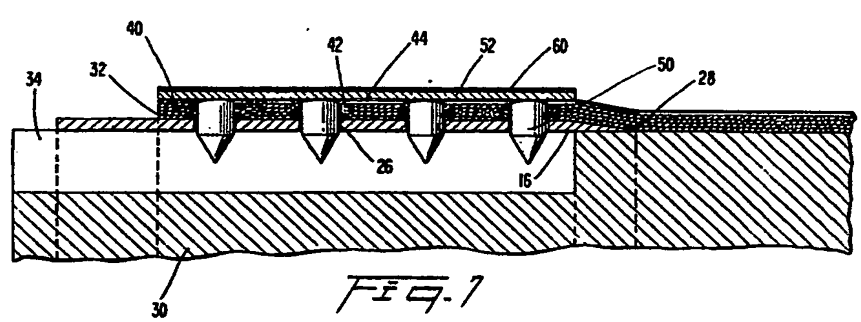

Fig. 7

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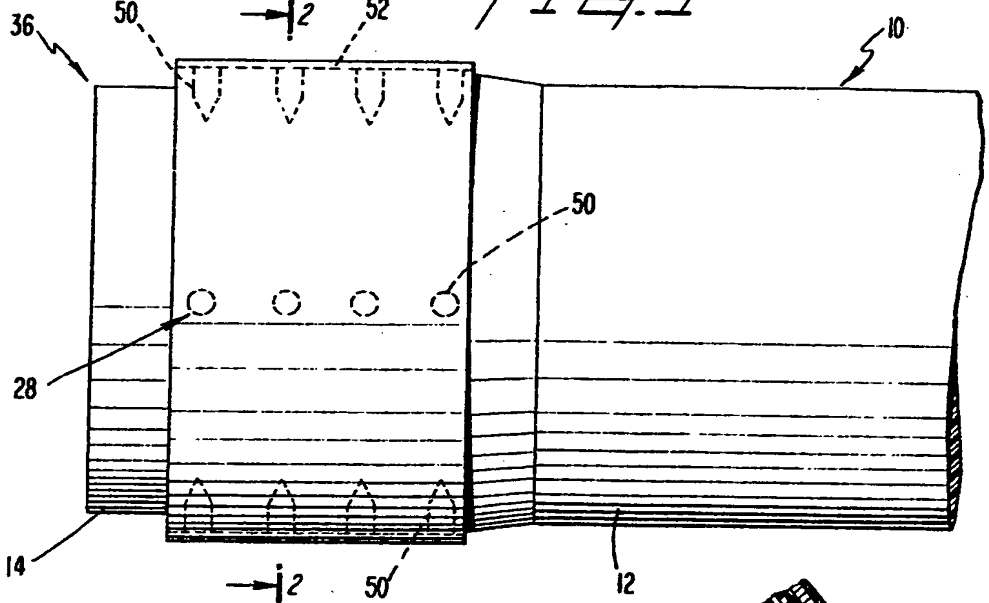

Fig. 1

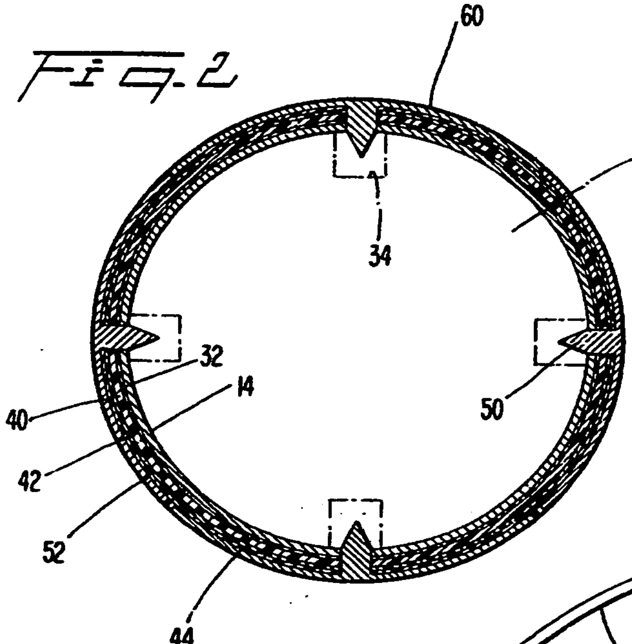

Fig. 2

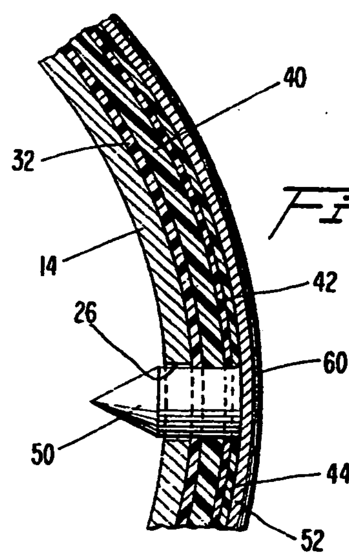

Fig. 3

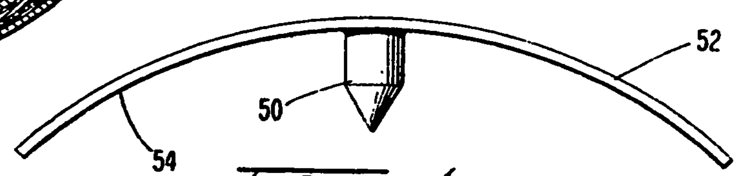

Fig. 4

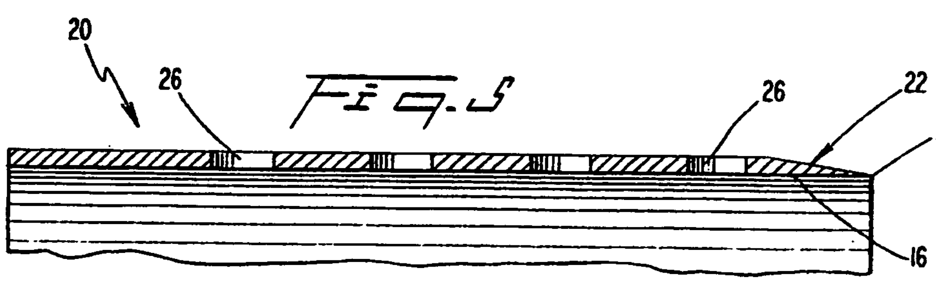

Fig. 5

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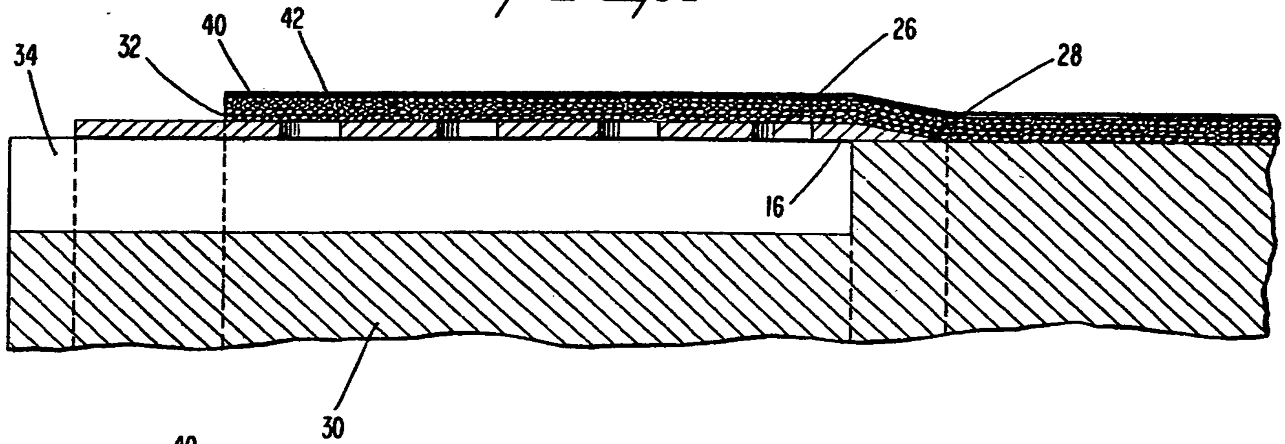
Fig. 6



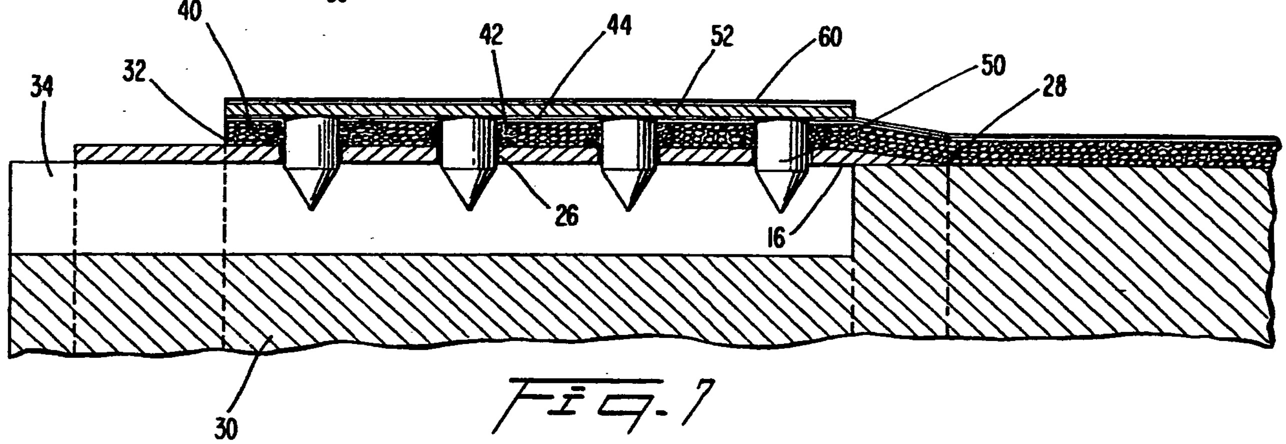


Fig. 7

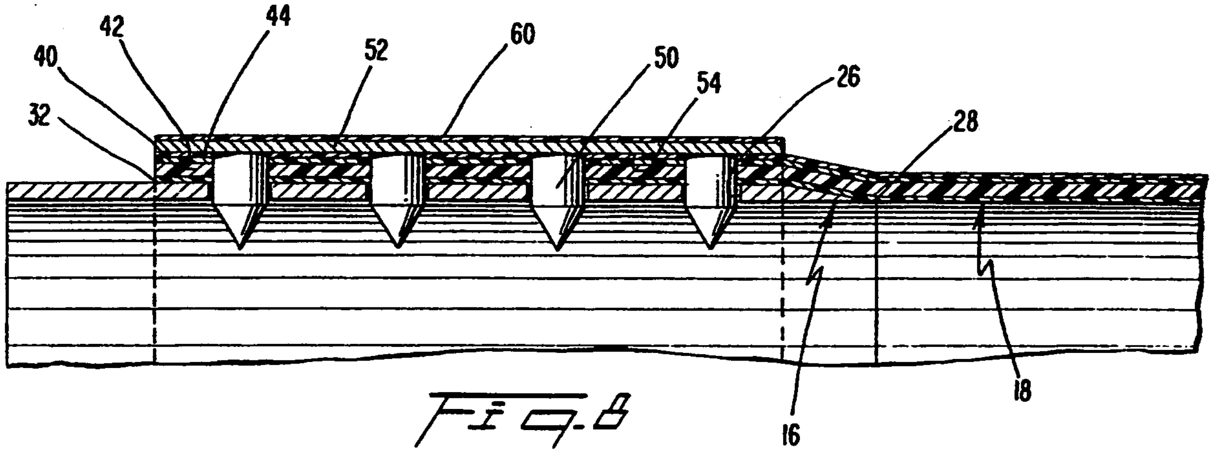


Fig. 8

SPECIFICATION
Fibr Reinforced Composite Shaft

This invention relates to fibre reinforced composite shafts and, more especially, to vehicle drive shafts comprising a fibre reinforced resinous shaft body with metallic coupling sleeves mounted at the ends thereof.

Tubular fibre reinforced composites have been heretofore proposed, as illustrated in U.S. Patent Nos. 2,882,072 (Noland) and 3,661,670 (Pierpont). In the Pierpont patent, for example, it has been proposed to form such composites from a resinous material which is reinforced by glass fibres. In particular, filaments bearing a non-hardened resinous material (i.e. an uncured thermosetting resin) are would around a mandrel until the desired thickness has been established. The reinforcing fibres can be positioned within the wall of the tubular composite in varying angular relationships. Thereafter, the resinous material is solidified (i.e. is cured). A premoulded threaded end portion can be mounted at the ends of the tubular composite, such as by the winding of filaments directly around the end portion during the winding process.

It recently has been proposed to form vehicle drive shafts from tubular fibre reinforced composites, as demonstrated by U.S. Patent No. 4,041,599 (Smith) and published Japanese Application No. 52-127542, entitled "Carbon Fibre Drive Shaft" which claims priority for the filing of U.S. Serial No. 676,856 on April 14, 1976 of Gordon Peter Morgan. In the Japanese application filaments bearing a non-hardened resinous material (e.g. an uncured thermosetting resin) are wound around a mandrel until the desired thickness has been established, whereupon the resinous material is cured. Zones or layers are positioned circumferentially within the wall of the shaft in the specific angular relationships there disclosed.

The above-mentioned Smith patent proposes the attachment of a carbon fibre reinforced epoxy drive shaft directly to a universal joint extension by a specific bonding technique.

Fibre reinforced composite shafts exhibit advantages over metallic shafts i.e. they are lighter in weight, more resistant to corrosion, stronger, and more inert.

In copending British Application No. 7910054 filed concurrently herewith entitled "Improved Carbon Fibre Reinforced Composite Drive Shaft", a fibre reinforced composite drive shaft is disclosed which exhibits improved service characteristics and the necessary strength and durability to withstand the various stresses encountered during vehicle operation. The disclosure of that copending application is her in incorporated by reference as if set forth at length.

Since direct welding or bonding of a resin shaft to metal does not normally create a suffici ntly strong and durable connection on a consistent and reliable basis, the use of metallic connector sleeves mounted at the ends of th shaft in accordance with the concept of the present invention provides a means for accomplishing a secure welded connection similar to that utilized with conventional metallic shafts.

The high torque leads which are to be transmitted by a vehicle drive shaft require that an extremely strong and durable torsional drive connection be established between the sleeves and shaft body. Previous proposals for mounting sleeves by employing adhesives or by wrapping the filament bundles around circumferential grooves on the sleeve periphery, cannot be relied upon to provide a connection of the requisite strength and durability.

It is, therefore, an object of the present invention to provide a novel, fibre reinforced resin shaft which minimizes or obviates problems of the types discussed above.

According to the invention, there is a method of forming a tubular fibre reinforced composite shaft comprising the steps of:

positioning a metal sleeve upon a segment of a mandrel;

applying fibrous material bearing a non-solidified resinous material upon said mandrel and the outer periphery of said sleeve;

inserting torque-transmitting elements inwardly through said previously applied fibrous material and into said sleeve;

applying retaining means around the outer ends of said torque-transmitting elements exteriorly of said previously applied fibrous material to retain said elements; and

solidifying said resinous material with said elements disposed in said fibrous material and said apertues to create a torsion-transmitting connection between said metal sleeve and said fibrous material; and removing said mandrel.

From another aspect the invention comprises a tubular fibre reinforced composite shaft comprising:

a shaft body comprising a plurality of integrally bonded plies of solidified fibre reinforced resinous material;

a metal sleeve in at least one end of said shaft body;

a plurality of torque-transmitting elements extending through at least one of said plies and said sleeve, to create a torsion-transmitting connection between said shaft body and said sleeve; and torque-transmitting element retaining means extending around the outer ends of said elements exteriorly of previously applied fibrous material to retain said elements.

In the accompanying drawings:—

Figure 1 is a side elevation of an end of a fibre r inforced composite shaft according to the present inv ntion;

Figure 2 is a cross-s ction on lin 2—2 of Figure 1;

Figur 3 is an enlarged fragmentary portion of Figure 2;

Figure 4 is a side elevational view of a torsion-transmitting member according to the present invention;

Figure 5 is a fragmentary, longitudinal section of the torsion-transmitting mechanism; and

Figures 6, 7 and 8 are fragmentary longitudinal sections of the shaft during various stages of fabrication.

In Figure 1 is shown one end of a drive shaft 10 embodying the present invention, which comprises a reinforced resin shaft body 12 of cylindrical cross-section, and a metal connector sleeve 14 secured, preferably, at each end of the shaft body.

The connector sleeve 14 is generally cylindrical and formed of an appropriate metal, such as steel or aluminum for example. The sleeve includes an inner annular surface 16 (Figure 8) of constant diameter which is substantially contiguous with an inner surface 18 of the shaft body located longitudinally inwardly thereof.

The inner end 20 of the sleeve 14 is tapered both longitudinally and radially inwardly at 22 (Figure 5) to provide a feather edge 24 for the reception of windings of reinforced resin material as will be discussed.

The sleeve contains a plurality of pre-formed apertures 26 (Figures 1 and 5) which are preferably aligned in circumferentially spaced, longitudinally extending rows 28, the rows being spaced by ninety degree. Of course, other suitable arrangements of the apertures are possible, as desired.

During fabrication of a preferred form of the shaft, a pair of connector sleeves are positioned on a mandrel 30 in a longitudinally spaced relationship. The sleeves engage the mandrel 30 (Figures 2, 6 and 8) snugly, but loosely enough to be removable therefrom. An appropriate clamping arrangement holds the sleeves 14 in place. The mandrel is coated with a release substance to resist the adherence thereto of resin or adhesives. Thereafter, the shaft body 12 is formed around both the mandrel and sleeve.

Construction of the shaft body 12 is preferably performed in a manner more fully described in the aforementioned copending British application No. 7910054. Summarized briefly, layers of fibre reinforced resin-impregnated material are applied, preferably in the form of bundles of substantially parallel continuous filaments bearing a non-solidified (i.e. liquid, soft and tacky, or molten) resinous material. The bundles can be dipped in an uncured liquid thermosetting resin, such as an epoxy resin, and then wound around the mandrel in multiple passes until a layer of desired thickness is established. Attention is further directed to U.S. Patent Nos. 3,661,670, 3,202,569, and 3,231,442 for additional details concerning possible arrangements for the clamping of sle ves and winding of filament bundles. The disclosur s of these patents are incorporated herein by reference as if set forth at length.

The term "layer" as used herein specifies a circumferential zone within the wall of the tubular drive shaft wherein the fibrous r inforcement is disposed in a specific configuration and differs from the adjac nt zone(s) with r spect to the configuration and/ r composition of the fibrous reinforcement. A single layer may include a multiple pass alignment or buildup of fibrous reinforcement in a given configuration. The term layer encompasses an alignment wherein the fibrous reinforcement is disposed therein at both plus and minus a given angle which optionally can be built up in multiple passes.

The fibres reinforce the thermoset resin matrix to impart necessary properties of strength and durability to the shaft. In this regard, glass fibres (e.g. E-glass or S-glass) and carbon fibres (i.e. either amorphous or graphitic) materials are preferred. The carbon fibres commonly contain at least 90 percent carbon by weight, and preferably at least 95 percent carbon by weight. Additionally, preferred carbon fibres have a Young's modulus of elasticity of at least 25 million psi (e.g. approximately 30 to 60 million psi).

The plies of filament bundles are wound in various orientation relative to the longitudinal axis of the drive shaft, and can be built-up to different thicknesses, respectively. Preferably, an initial layer of glass fibres is applied at an angle of from ± 30 to $\pm 50°$ relative to a line parallel to the longitudinal axis of the shaft. Next, a layer of glass fibres is applied at an angle of from 0 to $\pm 15°$. Thereafter, a layer of carbon fibres is applied at an angle of from 0 to $\pm 15°$. Then a layer of glass fibres is applied at about an angle of from about ± 60 to $90°$.

Of course the number and composition of layers, as well as their orientation and thickness may vary, depending upon the characteristics desired to be imparted to the shaft.

Rather than utilizing filament winding (e.g. wet winding or preimpregnated winding), other tube forming procedures can be employed, such as tube rolling, tape wrapping, or pultrusion, for example. In the former step, comparatively wide sections of resin impregnated tape are precut to patterns, stacked in sequence, and rolled ont the mandrel.

After the layers have been applied, the non-solidified resin is cured. In this regard, the resin may be of a self-curing type, or may be of a kind which cures in response to being subjected to heat and/or curing agent.

Relating more particularly to the present invention, the sleeve(s) 14 is positioned on the mandrel 30, such that the rows of apertures 26 are aligned with longitudinally outwardly open slots 34 (Figure 2) in the mandrel 30. Thereafter, an initial layer 32 (Figure 6) of glass fibres is wound around the mandrel and sleeves at about a ± 45 degree angle. This layer terminates short of the outermost end of the sl eve, so that the outer porti n 36 of the sleeve 14 remains exposed. The apertures 26 are circumferentially cover d by this layer 32.

Thereafter, a layer 40 of glass fibres is wound around the layer 32 at about a zero degree angle.

Next, a layer 42 of graphite fibres is wound around the layer 40 at about a zero degree angle.

Finally, a layer 44 of glass fibres is wound at about a 90 degree angle around the layer 42.

It will be understood that any number of layers can be applied and at various angles and thicknesses, depending upon desired shaft characteristics.

Next, a plurality of torque transmitting elements are inserted through the fibrous material and the sleeve 14. The torque transmitting elements comprise pins 50, preferably in the form of sharpened metal spikes, which are affixed at their outer ends to base plates 52. The plates 52 are arc-shaped and the spikes extend from concave surfaces 54 of the plate (Figure 4). Preferably, each plate 52 carries a plurality of spikes 50 arranged in a longitudinally extending row, in corresponding relation to the row 28 of apertures 26 in the sleeve 14.

A row of spikes is positioned externally of the outermost layer 44 of fibrous material, with the spikes aligned with the apertures 26 of the sleeve, and is pressed radially inwardly so as to penetrate the layers of fibrous material and enter the recesses 26. The spikes 50 project radially inwardly beyond the apertures 26 and into the slots 34 of the mandrel.

The base plate 52 abuts against the outermost layer 44 of fibrous material to limit inward travel of the row of spikes.

A plurality of rows of spikes 50 are inserted into corresponding apertures 26 of the sleeve, with the base plates 52 associated therewith disposed in circumferential end-to-end fashion to form a collar extending around the outermost layer of fibrous material. Preferably, there are four rows of spikes 50, with the base plate 52 thereof defining an arc of ninety degrees, although it will be understood that other arrangements of spikes may be utilized as desired.

After all of the spikes 50 have been pressed into position, a spike-retaining layer 60 of reinforced fibrous material bearing non-solidified resin is applied around the base plates 52 to retain the spikes 50 in position. Preferably, the layer 60 extends longitudinally inwardly only as far as the inner end of the base plates 52.

Thereafter, the non-solidified resin is cured to bond the layers together to form an integral composite, and the shaft is removed from the mandrel. Removal of the spikes 50 from the mandrel is accommodated by the open-ended slots 34 in the mandrel 30.

It will be appreciated that the above-described winding technique serves to mechanically lock shaft body 12 and sleeve 14 together. The spikes 50 serve to prevent longitudinal movement of the sleev 14 relative to the shaft body 12 and are capable of transmitting high torque loadings therebetween. Dislodgement of the spikes 50 is prev nted by the base plates 52 which limit radially inwardly travel of the spikes, and by the spike-retaining layer 60 of fibrous material which surrounds the base plates 52 and prevents radially outer travel of the spikes.

The sleeves 14 facilitate connection of the shaft to metal components such as metal yokes in a vehicle power train, since direct metal-to-metal welding contact is possible.

Although not essential, it might be desirable to apply an adhesive between the sleeve 14 and initial layer 32 of fibrous material to augment the connection therebetween.

Although the mechanical lock concept of the present invention is disclosed in conjunction with a particular shaft body, it is to be understood that this concept has utility with composite shafts in general wherein fibrous reinforcement is present in a resinous matrix material.

Claims

1. A method of forming a tubular fibre reinforced composite shaft comprising the steps of:

positioning a metal sleeve upon a segment of a mandrel;

applying fibrous material bearing a non-solidified resinous material upon said mandrel and the outer periphery of said sleeve;

inserting torque transmitting elements inwardly through said previously applied fibrous material and into said sleeve;

applying retaining means around the outer ends of said torque transmitting elements exteriorly of said previously applied fibrous material to retain said elements; and

solidifying said resinous material with said elements disposed in said fibrous material and said apertures to create a torsion-transmitting connection between said metal sleeve and said fibrous material; and

removing said mandrel.

2. A method according to claim 1, wherein said positioning step comprises positioning a metal sleeve having a plurality of apertures therein, and said inserting step comprising inserting said elements into said apertures.

3. A method according to claim 2, wherein said positioning step further comprises aligning said apertures of said sleeve with openings in said mandrel, and said inserting step further comprises pressing pointed ends of said elements through said fibrous material and into said openin.

4. A method according to claim 2 or claim 3, wherein said openings in said mandrel are open at their longitudinally outer ends.

5. A method according to any of claims 1 to 4, wherein said metal sleeve is in the form of an arc-shaped plate, said elements being affixed to a concave surface of the arc-shaped plate, and arranging a plurality of said plates with the circumferential ends of said plates in end-to-end relation to form a cylinder or part of a cylinder.

6. A method according to claim 5, wherein said elements are arranged in a longitudinally extending row on each said plate.

7. A method according to any preceding claim, wherein said last named applying step comprises applying additional fibrous material

bearing said non-solidified resinous material around the outer ends of said elements.

8. A method according to any of claims 1 to 7 wherein said elements are in the form of pins or spikes.

9. A method of forming a tubular fibre reinforced composite shaft comprising the steps of:

positioning a metal sleeve having a plurality of apertures therein upon a segment of a mandrel;

applying fibrous material bearing a non-solidified resinous material upon said mandrel and over said apertures in said sleeve;

inserting pins inwardly through said fibrous material and into said apertures such that plates affixed to outer ends of said pins abut said fibrous material, and

applying retainer means around said plates to retain said pins,

solidifying said resinous material with said pins disposed in said apertures to create a torsion-transmitting connection between said shaft body and said sleeves; and removing said mandrel.

10. A method according to claim 9, wherein said last-named applying step comprises applying additional fibrous material bearing said non-solidified resinous material around said plates.

11. A method according to claim 9 or claim 10, wherein said sleeve is positioned such that said apertures are aligned with openings in said mandrel.

12. A method according to any of claims 9 to 11, wherein said apertures are aligned with longitudinally outwardly open slots in said mandrel.

13. A method according to any of claims 9 to 12, wherein said pins are in the form of sharp spikes and the method involves pressing sharp spikes through said fibrous material into said apertures.

14. A method according to claim 13, wherein said spikes are affixed to concave surfaces of an arc-shaped plates which are arranged with circumferential ends of said plates in end-to-end relation.

15. A method according to claim 14, wherein said inserting step further comprises inserting spikes arranged in a longitudinally xtending row on each said plate.

16. A tubular fibre reinforced composite shaft comprising:

a shaft body comprising a plurality of integrally bonded plies of solidified fibre reinforcing resinous material;

a metal sleeve in at least one of said shaft body;

a plurality of torque transmitting elements extending through at least one of said plies and said sleeve, to create a torsion-transmitting connection between said shaft body and said sleeve; and

torque transmitting element retaining means extending around the outer ends of said elements xteriorly of previously applied fibrous material to retain said elements.

17. A shaft according to claim 16, wherein said elements have plates affixed at their outer ends, said element retaining means being disposed around said plates.

18. A shaft according to claim 17, wherein said plates are arcshaped, said elements extending from concave surfaces thereof, said plates arranged in circumferentially end-to-end fashion.

19. A shaft according to claim 17 or claim 16 to 19, wherein each plate carries a plurality of said elements arranged in a longitudinally extending row.

20. A shaft according to any of claim 17, wherein said elements are pins or sharpened spikes.

21. A method of forming a tubular fibre reinforced shaft substantially as hereinbefore particularly described and as illustrated in the accompanying drawings.

22. A tubular fibre reinforced shaft substantially as hereinbefore particularly described and as illustrated in the accompanying drawings.

23. A tubular fibre reinforced shaft manufactured by any of the methods claimed in claims 1 to 15.

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